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Water footprint of banana in the Brazilian semi-arid region[1]

Pegada hídrica da banana no semiárido brasileiro

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ABSTRACT - Due to water scarcity in semi-arid regions, water resources management strategies are indispensable for agricultural production, in order to guarantee food security for the population. Banana is of great importance in Brazilian agribusiness, with the Northeast region contributing the largest production, approximately 32% of national production. The objective of this study was to determine and evaluate the total water footprint of banana crop, considering the blue, green and gray water footprints, with a view to guiding water management in banana producing regions of the Brazilian semiarid region, in the State of Ceará, Brazil; in the Jaguaribe-Apodi and Tabuleiros de Russas Irrigation Projects, as well as a producing area in the municipality of Missão Velha. The average agricultural water footprint for Jaguaribe-Apodi, Tabuleiros de Russas and Missão Velha were 998.3; 1048 and 1107 $m^3\ t^{-1}$, respectively. For Missão Velha, the blue water footprint was 780.9 $m^3\ t^{-1}$ and for Jaguaribe-Apodi and Russas they were 830.6 and 862.7 $m^3\ t^{-1}$, respectively. The regions studied showed similar blue water footprint, which demonstrates the need for water input from the crop and the dependence on surface and/or underground water sources. Water footprint assessment contributes to the decision-making of governments and producers regarding the real value of raw water, raising discussions related to raw water collection in the agricultural sector as well as the implantation and management of crops in the different hydrographic basins.

Key words: Irrigation management. Efficient use of water. Water scarcity.

RESUMO - Devido à escassez hídrica em regiões semiáridas, estratégias de gestão dos recursos hídricos são indispensáveis para a produção agrícola, a fim de garantir a segurança alimentar da população. A banana possui grande importância no agronegócio brasileiro, com a região Nordeste contribuindo com a maior produção, aproximadamente 32% da produção nacional. Objetivou-se determinar e avaliar a pegada hídrica total da cultura da bananeira, considerando as pegadas hídricas azul, verde e cinza, com vistas a orientar o manejo da água em regiões produtoras do semiárido brasileiro, no Estado do Ceará, Brasil; nos Projetos de Irrigação Jaguaribe-Apodi e Tabuleiros de Russas, além de uma área produtora no município de Missão Velha. As médias de pegada hídrica agrícola para Jaguaribe-Apodi, Tabuleiros de Russas e Missão Velha foram de 998,3; 1048 e 1107 $m^3\ t^{-1}$, respectivamente. Para Missão Velha, a pegada hídrica azul foi de 780,9 $m^3\ t^{-1}$ e para Jaguaribe-Apodi e Russas foram de, respectivamente, de 830,6 e 862,7 $m^3\ t^{-1}$. As regiões estudadas apresentaram pegada hídrica azul semelhantes, o que demonstra a necessidade de aporte hídrico da cultura e a dependência de fontes hídricas superficiais e/ou subterrâneas. A avaliação da pegada hídrica contribui com a tomada de decisão de governantes e produtores quanto ao real valor da água bruta, elevando as discussões relacionadas à cobrança de água bruta no setor agrícola e à implantação e manejo das culturas nas diferentes bacias hidrográficas.

Palavras-chave: Manejo de irrigação. Uso eficiente da água. Escassez hídrica.

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INTRODUCTION

Water scarcity results in increased competition for water, which restricts agricultural production and negatively affects income and livelihood opportunities for many residents of rural and urban areas. A major challenge for farmers will be to increase production, even with limited land and water availability, through technology and management practices. Understanding water consumption is crucial for the sustainable management of water resources and, in the current scenario, the need for public policies that ensure efficiency and equity in water resources tends to increase (MEKONNEN; HOEKSTRA, 2016; NOURI *et al*., 2019; NOVOA *et al*., 2019).

In Latin America, water availability is being threatened by several factors, including population growth, rapid urbanization, water contamination and increased water demand. As a consequence of population growth and economic development, there is a greater imbalance between the demand and supply of global water resources (HUANG *et al.*, 2015).

In order to measure the volume of water required by all goods consumed by people in a country, Hoekstra (2003) introduced the term “water footprint” (WF). To quantify the volume of water related to a product, this term has evolved over the years, incorporating the concepts of green water, blue water and gray water. Hoekstra *et al.* (2011) defined green water as that from rain, stored in the soil, and available for plant development. Blue water is that stored in surface and underground reservoirs and used in production processes and gray water, in turn, is that necessary to dilute the pollutant load from production processes.

Agricultural production contributes a high proportion of the global water footprint of food products. In this way, agriculture has the great challenge of improving water management to support the growth of world population, boost economic growth and reduce environmental impacts (CAZCARRO *et al*., 2015; COLTRO; KARASKI, 2019).

The percentage value of each water footprint component (green, blue or gray) depends on the type of crop, water management system, production site, soil and local climate. The banana crop requires specific management to ensure the proper development of plants, and irrigation is necessary due to the high water demand of banana trees (ROIBÁS; ELBEHRI; HOSPIDO, 2015). In this context, it is important to evaluate the water footprint of bananas produced in the main fruit growing centers in the State of Ceará, with emphasis on the main production centers such as the Irrigation Projects of Jaguaribe-Apodi, Tabuleiros de Russas and Missão Velha.

In view of the above, the objective was to determine and evaluate the total water footprint of the banana crop, considering the blue (WFblue), green (WFgreen) and gray (WFgray) water footprints. This guides the management of water in producing regions of the Brazilian semiarid area such as the main production centers of the State of Ceará, the Jaguaribe-Apodi Irrigation Projects (Limoeiro do Norte), Tabuleiros de Russas (Russas), in addition to production areas in the municipality of Missão Velha, considering the agricultural process exclusively.

MATERIAL AND METHODS

The research followed the methodology proposed by Hoekstra *et al.* (2011), described in the water footprint assessment manual, for assessing the water footprint of the banana crop cultivation process under irrigation, in the field production phase.

Characterization of banana producing areas in the State of Ceará

In the study, a sample of four producers was selected in the Jaguaribe-Apodi Irrigation Project, four in the Tabuleiros de Russas Irrigation Project (sub-basin of Baixo Jaguaribe) and three in the municipality of Missão Velha (Salgado River basin). These producers are representative of the technological levels adopted for the banana crop production systems.

Technological level

The Secretary of Irrigated Agriculture of the State of Ceará (Seagri) adopted two technological levels for banana crop production systems: technological level 1 (TL1) - high-tech production system aimed at producers and entrepreneurs with areas and/or production volumes that allow the use of mechanized equipment, modern technologies and supplies recommended by research and that possess a high level of business management and control; technological level 2 (TL2) - medium to high technology production system, aimed at producers with areas and/or production volumes that allow little use of mechanization, greater employment of labor with simplified management and control (CEARÁ, 2003).

Information on the samples of the producers selected in the study is available in Table 1.

Jaguaribe-Apodi Irrigation Project

The Jaguaribe-Apodi Irrigation Project is located in Chapada do Apodi, in the State of Ceará, municipality of Limoeiro do Norte, between coordinates 5° 20’ South latitude and 38° 05’ West longitude. The climate in the region is BSw’h’, with an average annual temperature of 28.5 °C, with a minimum of 22 °C and a maximum of 35 °C. The average annual relative humidity of the air is 62%. The average annual precipitation is 772 mm, with irregular rainfall distribution and water supply from the Castanhão Reservoir. At the study site, the Prata Catarina variety is cultivated, using localized irrigation by micro-sprinkling in soil with a sandy loam texture on the surface to clay loam at a depth of 0.30 m, as shown in Table 2.

Tabuleiros de Russas Irrigation Project

The Tabuleiros de Russas Irrigation Project has water supply from the Castanhão reservoir and is located in the municipalities of Russas, Limoeiro do Norte and Morada Nova, in the sub-basin of Baixo Jaguaribe, South latitude 5° 37', West longitude 38° 07'. The climate type is Bsh, according to the Köppen classification and is dry, very hot and with rainfall volume of around 720 mm, distributed irregularly throughout the year (rainy season). Banana cultivation occurs with several technological levels in light-textured soil, according to the physical attributes presented in Table 3.

Missão Nova (Missão Velha)

The producers are located in the Salgado River basin, in Missão Nova district, in the southeast of the State of Ceará. The area is located in the municipality of Missão Velha, with latitude of 7° 19' South and longitude of 39° 11' West. In 2017, approximately 1715 ha of banana trees were installed at this location, irrigated with an underground water source.

Table 1 - Sample information from selected producers

Identification	Location	Area (ha)	Soil	Mean productivity (kg ha^{-1})	Technological level
P01 LN	Limoeiro do Norte	12.0	Sandy clay loam	39.840	TL1
P02 LN	Limoeiro do Norte	4.0	Sandy clay loam	18.600	TL2
P03 LN	Limoeiro do Norte	8.0	Sandy clay loam	25.200	TL1
P04 LN	Limoeiro do Norte	12.0	Sandy clay loam	37.440	TL1
P01 R	Russas	4.0	Sandy loam	18.600	TL2
P02 R	Russas	12.0	Sandy loam	33.085	TL1
P03 R	Russas	32.0	Sandy loam	38.880	TL1
P04 R	Russas	8.0	Sandy loam	24.292	TL2
P01 MV	Missão Velha	4.0	Sandy loam	18.602	TL2
P02 MV	Missão Velha	20.0	Sandy loam	34.800	TL1
P03 MV	Missão Velha	7.5	Sandy loam	25.200	TL1

*Areas with micro sprinkler irrigation

Table 2 - Physical attributes of the soil in Chapada do Apodi

	Granulometric composition (g kg^{-1})				
Depth (m)	Coarse sand	Fine sand	Silt	Clay	Texture classification
(0 – 0.10)	355	207.5	265	172.5	Sandy loam
(0.10 – 0.20)	335	207.5	212.5	245	Sandy clay loam
(0.20 – 0.30)	255	177.5	240	327.5	Clay loam

Table 3 - Physical attributes of the soil of the Tabuleiros de Russas Irrigation Project

	Granulometric composition (g kg^{-1})				
Depth (m)	Coarse sand	Fine sand	Silt	Clay	Texture classification
(0 – 0.10)	425	449	43	83	Sandy loam
(0.10 – 0.20)	423	435	39	102	Sandy loam
(0.20 – 0.30)	416	397	38	149	Sandy loam

Rainfall in the region, with an annual average of 1075.8 mm, is concentrated in the period from January to April. The predominant climate is hot and humid (Aw), with edaphoclimatic conditions favorable to the development of the banana crop (MEDEIROS *et al.*, 2013).

Water footprint assessment method

The methodology of Hoekstra *et al*. (2011) was used to assess the water footprint of the irrigated banana cultivation process, in its field production phase, which consists of four phases: definition of objectives and scope, water footprint accounting, water footprint sustainability analysis and formulation of strategic responses.

Calculation of the green, blue and gray water footprint

The blue water footprint (WFblue, m³ or L) is an indicator of the consumptive use of what is called blue water, that is, fresh surface or groundwater. The blue and green water footprint at one stage of the process is calculated from Equations 1 and 2, respectively:

$$WF_{blue} = Evaporation_{blue} + Incorporation_{blue} + Return\ flow_{blue} \quad (1)$$

$$WF_{green} = Evaporation_{green} + Incorporation_{green} + Return\ flow_{green} \quad (2)$$

The gray water footprint is calculated by dividing the pollutant load (L, masstime^{-1}) by the difference between the concentration of the environmental standard of water quality for a given pollutant (the maximum acceptable concentration Cmax, in mass volume^{-1}) and its natural concentration in the receiving water body (Cnat, mass volume^{-1}), Equation 3.

$$WF_{gray} = \frac{L}{C_{\max} - C_{nat}} \quad (3)$$

The calculation of the total water footprint of a crop or tree development process is performed according to Equation 4:

$$WF_{proc} = WF_{proc.blue} + WF_{proc.green} + WF_{proc.gray} \quad (4)$$

Generally, water footprint processes in the agricultural and forestry sectors are expressed in m³ t^{-1}, equivalent to L kg^{-1}.

The green component of the water footprint of the growth process of a plantation or forest (WFproc.green, m³ t^{-1}) is calculated as the green component of the crop's water demand (CWDgreen, m³ ha^{-1}) divided by the crop productivity (Prtv, t ha^{-1}), Equation 5. The blue component (WFproc.blue, m³ t^{-1}) is calculated in a similar way.

$$WF_{proc.green} = \frac{CWD_{green}}{\mathrm{P}rtv} \quad (5)$$

The gray component of the growth water footprint of a plantation or forest (WFproc.gray, m³ t^{-1}) is calculated according to Equation 6:

$$WE_{proc.gray} = \frac{\frac{(\propto AR)}{C_{\max} - C_{nat}}}{\mathrm{P}rtv} \quad (6)$$

where: WFproc.gray - is the gray component of the water footprint for the growth of a plantation or forest (m³ t^{-1}); AR - application rate per hectare of agrochemicals in the field (kg ha^{-1}); α - leaching/runoff fraction; Cmax - maximum acceptable concentration (kg m^{-3}); Cnat- natural pollutant concentration (kg m^{-3}) and Prtv - crop productivity (t ha^{-1}).

For agricultural gray water footprint calculation, nitrogen was considered as the critical contaminant, using the values of applied fertilizers that are available in the global FERTISTAT database (FAO, 2017). A leaching/runoff fraction of this contaminant of 10% of the total N applied in the field was assumed, according to the recommendations of the manual proposed by Hoekstra *et al.* (2011).

FAO recommends an application of N for the banana crop between 200 and 400 kg ha^{-1} year^{-1}.

Study frontier

The frontier of this study is the agricultural production of bananas. Banana production refers to an average year of production, considering the data of the preparation phases of the area and planting, growth and stabilization of the orchard with a shelf life of 10 years.

In the agricultural production inventory, data were obtained on the following production phases: i) Preparation of the area: change of land use, with transformation of the vegetation from caatinga to banana; ii) Planting: implementation and formation of the orchard in the first year of cultivation; iii) Formation or growth: considering the development of the plant in the second year of cultivation; and iv) Stabilization, which occurs with the stabilization of the orchard's production from the third year onwards.

According to Hoekstra *et al*. (2011), to calculate the water footprint, the life cycle is used, however, in this study, the water footprint of the development of a crop in the field was evaluated not counting, therefore, the water footprint of the supplies of inputs to be used in production.

Data collection

In the agricultural production phase, the procedures used may vary depending on factors such as: climatic conditions, available and used technologies, and the presence of pests and diseases in the crop. However, according to information obtained in farm units in three irrigation projects, it was possible to determine a general procedure, commonly used in the region that will be applied in this study.

RESULTS AND DISCUSSION

Climatic conditions

The reference evapotranspiration (ETo) and effective precipitation (EP) data from the Morada Nova meteorological station, expanded to the municipalities of Limoeiro do Norte and Russas, are available in Figure 1. The average total ETo is 2245.04 mm year^{-1}, which corresponds to 22,450.4 m³ ha^{-1} year^{-1}, and with an average total EP of 294.62 mm year^{-1}, which corresponds to 2946.2 m³ ha^{-1} year^{-1}. It is possible to observe that there is a deficit of approximately 19,504.2 m³ ha^{-1} year^{-1}, making the adoption of irrigation essential.

The ETo and EP data for the Barbalha region are shown in Figure 2. The average total ETo is 2130.61 mm year^{-1}, which corresponds to 21,306.10 m³ ha^{-1} year^{-1}, and an average total EP of 623.81 mm year^{-1}, which corresponds to 6238.10 m³ ha^{-1} year^{-1}. It is possible to observe that there is a deficit of approximately 15,068.0 m³ ha^{-1} year^{-1} in the region.

Irrigation patterns

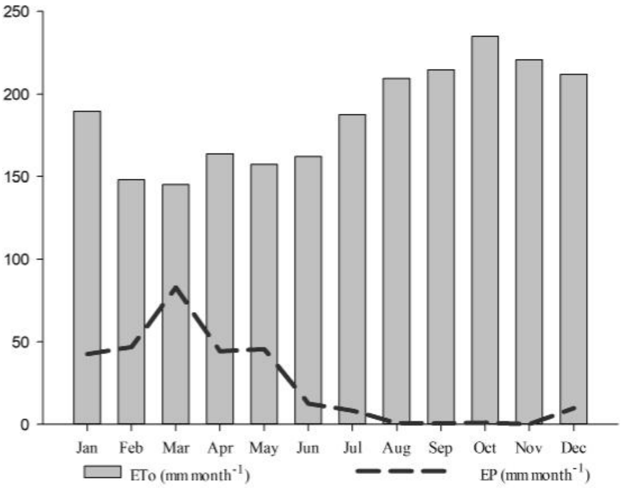
The irrigation pattern followed by the producers in Russas, Apodi and Missão Velha indicates that all the producers use the irrigation strategy with daily frequency in the dry season, with a localized irrigation system type microsprinkler, and complementary irrigation in the rainy season.

Jaguaribe-Apodi producers are located in an irrigation project, with their own management and collective water distribution, daily water supply to carry out their activities, as well as daily irrigation of 15 h.

Table 4 presents, for the different localities, the irrigation patterns inherent to the analyzed producers.

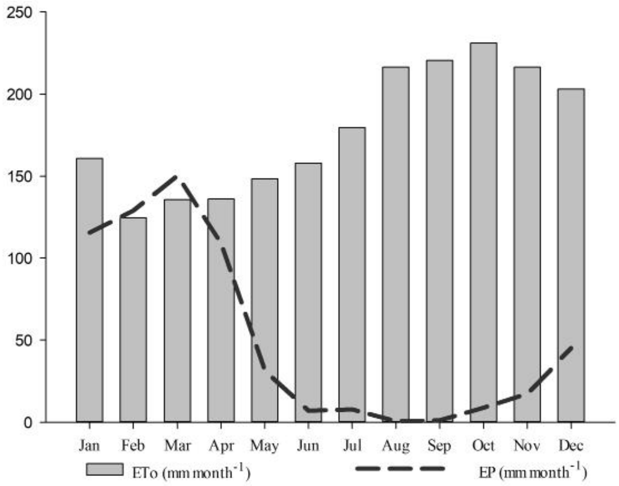
The irrigating farmers of the Tabuleiros de Russas Irrigation Project also have their activities in a public irrigation project, with individual water distribution, for 20 h day^{-1}, making it possible to decide when and how much to irrigate. The irrigating farmers of Tabuleiros de Russas use a daily irrigation shift with several installments during the day, due to the low water retention capacity of the soil. Producers in the region of Missão Velha carry out their irrigation with a daily shift, but with smaller installments during the day.

Figure 1 - Reference evapotranspiration, in mm month^{-1}, estimated by the Penman-Monteith methodology (1991) for the municipality of Morada Nova in the period 1937 – 2016



Source: Adapted from BDMEP - INMET (2016)

Figure 2 - Reference evapotranspiration, in mm month^{-1}, estimated by the Penman-Monteith methodology (1991) for the municipality of Barbalha in the period 1973 – 2016



Source: Adapted from BDMEP - INMET (2016)

Table 4 - Irrigation patterns described by the analyzed producers

Location	Irrigation pattern	Nº of producers
Jaguaribe-Apodi	B	3
	A	1
Tabuleiros de Russas	C	4
Missão Velha	C	3

* Patterns: A - 7 days a week in the dry season and once every 3 weeks in the rainy season; B - 7 days a week in the dry season, once every 2 weeks in the rainy season; C - 7 days a week in the dry season, once every 1 week in the rainy season

Yield

The average production of the evaluated areas (Figure 3) in Jaguaribe-Apodi is 30.27 t ha^{-1} year^{-1}, while FAO (2015a) indicates in its database that Brazil had an average of 14.37 t ha^{-1} year^{-1}, between the years 2012-2015. FAO data also showed that the average for the region studied is 22.10 t ha^{-1} year^{-1}, between the years 2012-2015, it also includes areas under rainfed banana cultivation. The sample from Limoeiro do Norte is 111% higher than the average presented by FAO. One of the reasons why the average of irrigating farmers is higher than the national and regional average is due to the greater application of technology and crop management, another reason is that the average presented by FAO also includes areas under rainfed banana cultivation in dryland.

The average income of producers in Tabuleiros de Russas is 26.20 t ha^{-1} year^{1}, 82% higher than the average presented by FAO (2015a). For the region of Missão Velha, the average income of producers is 28.71 t ha^{-1} year^{1}; therefore, it is 100% higher than the average presented by FAO for Brazil, which is 14.37 t ha^{-1} year^{-1}.

It is important to note that the average yield of Jaguaribe-Apodi is 15 and 5% higher, respectively, than the yields observed in Missão Velha and Russas.

On the other hand, the average yield of the producers in Missão Velha, when compared to that of Russas, recorded approximately 10% higher yield. Despite the technologies adopted by the irrigators of the Tabuleiros de Russas, the water scarcity that lasted from 2012 to 2017 influenced the drop in banana yields in the Russas region, which was on average 30%.

Evapotranspiration

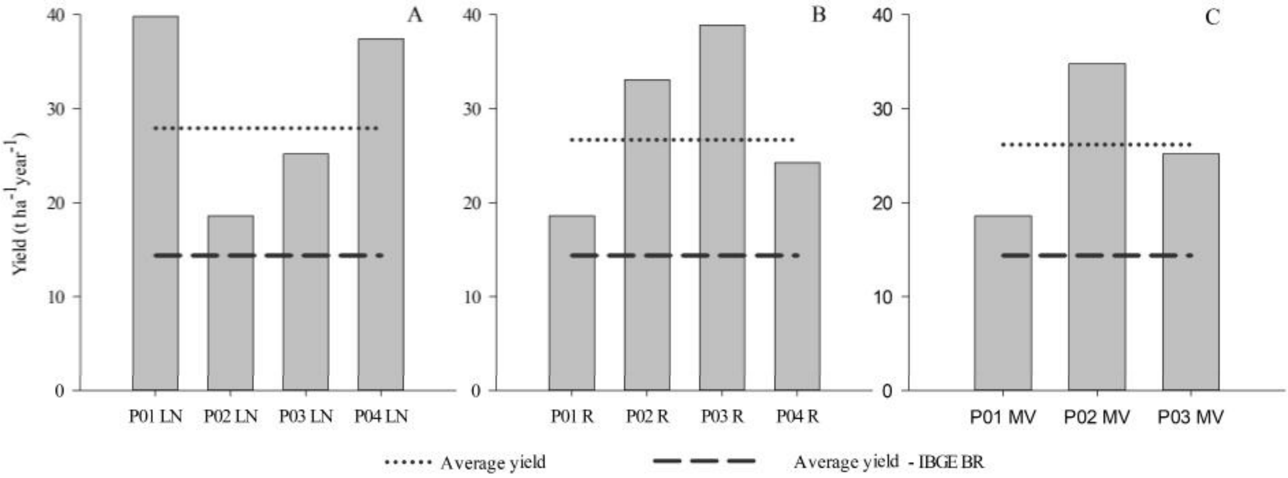
The evapotranspiration expressed in m³ ha^{-1} year^{-1} was obtained by directly transforming the evapotranspiration value into mm year^{-1}, which is equivalent to the volume of green and blue water consumed per hectare in the agricultural phase. The gray agricultural footprint was calculated based on the amount of N application reported for the conventional banana produced in the analyzed locations.

The average evapotranspiration calculated for the localities of Jaguaribe-Apodi and Tabuleiros de Russas was 22,450.4 m³ ha^{-1} year^{-1}, while for the region of Missão Velha it was 21,306.1 m³ ha^{-1} year^{-1}. These rates are close to the evapotranspiration for the banana crop, which according to FAO (2015b) is around 22,000 m³ ha^{-1} year^{-1} in dry tropics. The difference in evapotranspiration values between the analyzed locations is mainly due to climatic conditions.

It can be seen in Figure 4 that for the region of Apodi and Russas, in the period from January to May, the water supply of the crop depends on the supply of irrigation water, which increases the WFblue in this period. For the region of Missão Velha, for the same period, the water supply is carried out by rainwater, indicating that in this area the WFgreen is higher. In the second semester, the two regions are equivalent and the water supply is predominantly carried out by irrigation.

Table 5 shows that for every 1.0 m³ of blue water consumed in Jaguaribe-Apodi and in Russas, 0.53 m³ is consumed in Missão Velha. It should be noted that such consumption refers to the blue water evapotranspired by the crop (from irrigation), not from the extraction of water for irrigation. The extraction of water for irrigation is certainly much higher, however the methodology proposed by Hoekstra for the agricultural phase only accounts for evapotranspired water.

Figure 3 - Yield (t ha^{-1} year^{1}) obtained by samples from producers in: A - Limoeiro do Norte (LN), B - Russas (R) and C - Missão Velha (MV) for the year 2015



The value of the gray water demand calculated for conventional agricultural practices in the Irrigation Projects of Jaguaribe-Apodi, Tabuleiros de Russas and in Missão Velha corresponds to the water required for the assimilation of nitrogen load from the applied fertilizers; however, the effect that the runoff generated by the excessive irrigation will have on nutrients in the field is unknown.

Water footprint

The water footprint, expressed in $m^3\ t^{-1}$, was obtained from the relationship between the water demand ($m^3\ ha^{-1}$) in the production phase and the crop yield in $t\ ha^{-1}$ (Table 6).

The total water footprints for producers in Apodi vary between 708.77 and 1448.79 $m^3\ t^{-1}$, between 738.19 and 1462.21 $m^3\ t^{-1}$ for Russas and between 802.22 and 1438.07 $m^3\ t^{-1}$ for Missão Velha.

The largest average green water footprint for the three regions was Missão Velha, which is 998.28 $m^3\ t^{-1}$, surpassing Jaguaribe-Apodi (106.99 $m^3\ t^{-1}$) and Tabuleiros de Russas, by 137 and 118%, respectively (111.13 $m^3\ t^{-1}$).

The average monthly green (WFgreen) and blue (WFblue) water footprints are shown in Figure 5, for the Limoeiro do Norte/Russas and Missão Velha samples. It is

Figure 4 - A - evapotranspiration values of banana cultivation for samples from Jaguaribe-Apodi (LN) and Tabuleiros de Russas (R); B - evapotranspiration values from banana cultivation for samples from Missão Velha

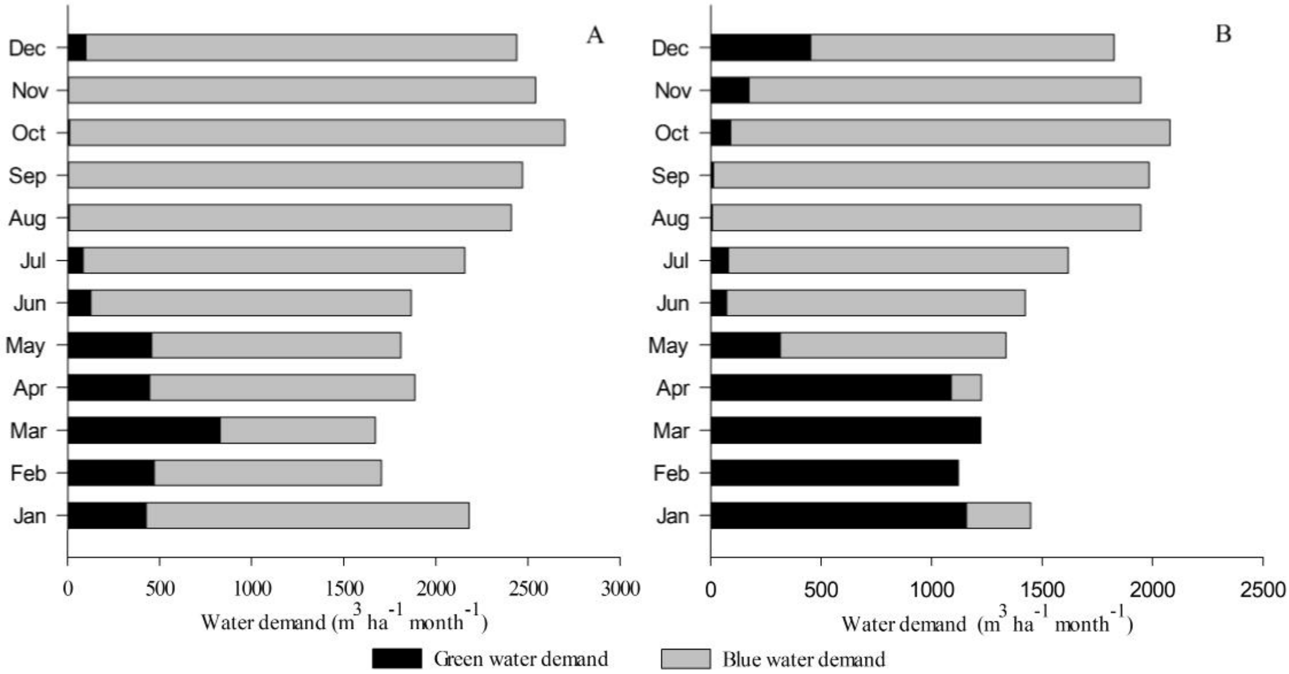


Table 5 - Water demand of banana in the agricultural phase ($m^3\ kg^{-1}\ year^{-1}$) – average for the samples in Jaguaribe-Apodi (Limoeiro do Norte), Tabuleiros de Russas (Russas) and Missão Velha

Water demand in the agricultural phase	Jaguaribe-Apodi	Tabuleiros de Russas	Missão Velha
Green water demand	133.31	133.31	236.92
Blue water demand	1034.87	1034.87	548.42

Table 6 - The average water footprint of the agricultural phases for the Jaguaribe-Apodi, Tabuleiros de Russas and Missão Velha samples ($m^3\ t^{-1}$)

Water footprint	Jaguaribe-Apodi	Russas	Missão Velha
Green water footprint	106.99	111.13	254.05
Blue water footprint	830.56	862.69	780.92
Gray water footprint	60.73	74.15	71.94
Total water footprint	998.2	1047.97	1106.91

observed that WFgreen in both regions is concentrated in the first half of the year, but only in the region of Missão Velha was all the crop demand met by the rainfall in the months of February and March. However, the WFblue for the Jaguaribe-Apodi/Russas region exceeds by 19.3% the WFblue for the Missão Velha region.

When observing the blue water footprint (WFblue), the surveys identified a larger footprint in the Tabuleiros de Russas, which is 862.69 m³ t^{-1}, followed by the Jaguaribe-Apodi, with a WFblue of 830.56 m³ t^{-1}, and Missão Velha with 780.92 m³ t^{-1}, this is due to climatic conditions, which demand lower blue water evapotranspiration. The average total WF (blue, green and gray) obtained for the Jaguaribe-Apodi Irrigation Project was 998.28 m³ t^{-1}, which is 4.7% below the values found in the Russas Irrigation Project, which was 1047.97 m³ t^{-1}, and 9.8% lower than the values found in the Missão Velha irrigation hub, of 1106.91 m³ t^{-1} (Figure 6).

Clercx, Torres and Kuiper (2016), evaluating the water footprint of bananas produced by small banana producers in Peru and Ecuador, found that the average water footprint of the Ecuadorian sample was 576 m³ t^{-1} and for the Peruvian sample it was 599 m³ t^{-1}. In the Peruvian case, 94% of the average water footprint corresponds to the WFblue, that is, from irrigation, but for Ecuador, the WFblue corresponds to 34% of the total. In both countries, the agricultural production phase contributes more than 99% to the total water footprint.

In a study in Ecuador, the water footprint of bananas was 302 L kg^{-1} of bananas, considering only blue and green water. To reach the final consumer, the blue and green water footprint of 1 kg of banana was 330 L kg^{-1} (ROIBÁS; ELBEHRI; HOSPIDO, 2015).

Pahlow, Snowball and Fraser (2015), studying the agricultural water footprint of South Africa based on data for the period 1996 to 2005, concluded that the banana crop has a green, blue and gray water footprint, respectively, of 288; 431 and 29 m³ t^{-1}, totaling a water footprint for the crop of 748 m³ t^{-1}.

By correlating the world WFgreen (660 m³ t^{-1}) with the WFgreen for the three regions studied: Missão Velha (254.05 m³ t^{-1}), Limoeiro do Norte (106.99 m³ t^{-1}) and Russas (111.13 m³ t^{-1}), it was observed that the regional values are surpassed by the average global WFgreen, which justifies the strong impact of the WFblue for the regional banana production.

The world's average consumption of virtual water in banana production was determined to be 790 m³ t^{-1} (MEKONNEN; HOEKSTRA, 2011). The average WFtotal obtained for the Jaguaribe-Apodi Irrigation Project samples was 998.28 m³ t^{-1}, in the Russas Irrigation Project, which was 1047.97 m³ t^{-1}, and in the Missão Velha irrigation project it was 1106.91 m³ t^{-1}, increased by WFblue, and greater than world consumption in 26; 33 and 40%, respectively.

Figure 5 - Agricultural water footprint of bananas in m³ t^{-1} for the samples from Limoeiro do Norte and Russas (A) and Missão Velha (B)

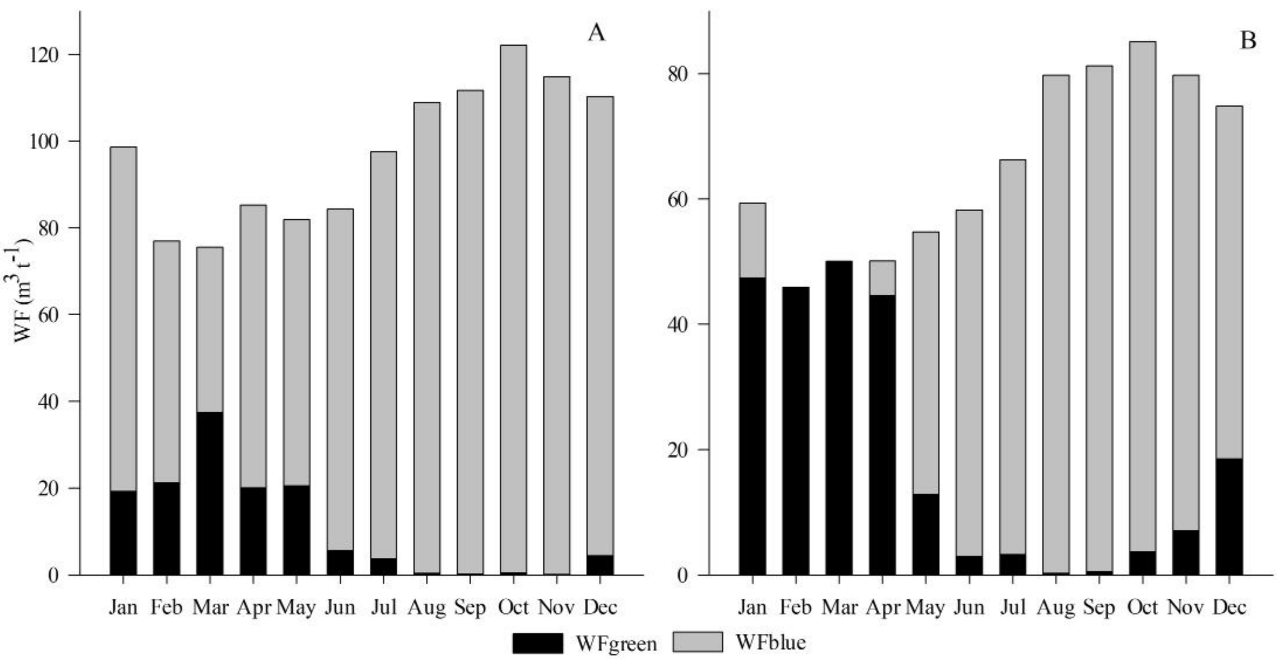
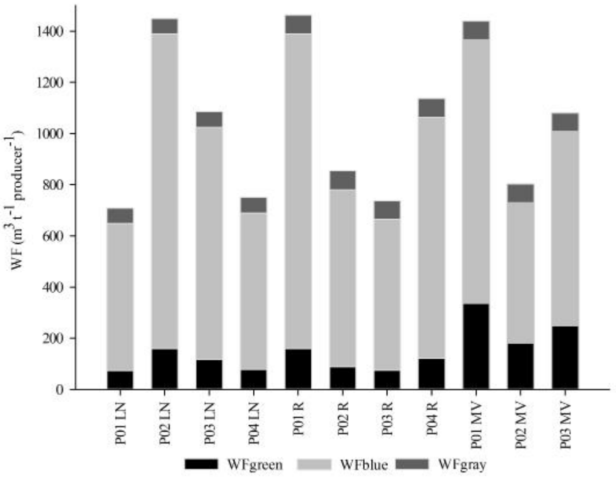


Figure 6 - Agricultural water footprint of bananas in m³ t^{-1} for the samples of producers in Limoeiro do Norte (LN), Russas (R) and Missão Velha (MV)



Giacomin and Ohnuma Júnior (2012), when analyzing the result of the water footprint by countries and specific products (corn, soy, rice, chicken meat, goat meat, beef), concluded that in developing countries the water footprint varies, generally, not because of their large relative consumption of water, but, above all, large water footprints are observed per ton of product consumed, that is, due to a low water productivity. Another factor that the authors highlighted is the low yields in agricultural production combined with the high rates of evapotranspiration in the countries.

Cazcarro *et al.* (2015) compared the most important levels of the water footprint structure in Agriculture in Spain between 2005 and 2010. This period brings together the most important changes that have occurred, among others, in terms of the expansion of irrigation, harvesting and construction of water infrastructure in Spain. These changes, analyzed at the regional level, were mainly related to the environmental and economic sustainability of water.

Chouchane *et al.* (2015) quantified and analyzed Tunisia's water footprint at the national and subnational levels, assessing the green, blue and gray water footprints for the period 1996 to 2005. The authors also assessed the economic productivity of water and land related to crop production (olives, barley, carrots, figs, grapes, oranges, potatoes, tomatoes, wheat and other crops) for irrigated and rain-fed agriculture, and water shortages. The water footprint of Tunisian agricultural production made the largest contribution (87%) to the total national water footprint. Tomatoes and potatoes were the main crops with relatively high productivity in terms of water savings, while olives and barley were the main crops with relatively low productivity.

Huang *et al.* (2015) using the water footprint approach assessed the impact of the agricultural production of maize and wheat crops in the Beijing Region. According to the authors, the traditional areas of corn and wheat crops could be increased, however, current agricultural practices, which involve excessive irrigation and fertilization lead to water waste and worsening leaching pollution. Based on field experiences, the study provided evidence for reducing the water footprint and improving agricultural practices for cereal cultivation in Beijing in a situation of water scarcity. The reduction of 33.3% in the volume of irrigation water, applied to corn and wheat crops, in situations of scarcity, can reduce the water footprint by 27.5% without significant productivity losses.

It is worth noting the importance of the crop in the State of Ceará, where the harvested area corresponded to 49,225 hectares in 2015, that is, 9.3% of the national area, with a production of 375,533 t, corresponding to 5.6% of the total production in the country, which contributes to the generation of employment and income. It is believed that a direct job is created for every two hectares of plantation, while two others are generated indirectly for that same planted area.

In summary, the agricultural water footprint is sensitive to the crop production level, therefore, it is important that the applied cropping system generates the highest productivity in order to reduce the water footprint per ton of banana produced. It is worth noting that the water footprint assessment is an important indicator and that it must analyze a set of other indicators such as, for example, the water scarcity index of the hydrographic basins where the production areas are installed.

CONCLUSIONS

1. The three regions studied showed similar WFblue, which demonstrates the need for water supply to the crop and the dependence on surface and/or underground water sources;
2. Evaluation of the water footprint contributes to the decision-making of governments and producers regarding the real value of raw water, raising discussions related to the collection of raw water in the agricultural sector and the implementation and management of crops in the different hydrographic basins.

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